I. AMENDMENT

IN THE SPECIFICATION:

Please amend the specification as follows:

[9] The coils are energized in sequences to produce a current path through two coils of the "Y", with the third coil left floating (or in tri-state), hereinafter floating coil FC. The sequences are arranged so that as the current paths are changed, or commutated, one of the coils of the current path is switched to float, and the previously floating coil is switched into the current path. The sequences are defined such that when the floating coil is switched into the current path, the direction of the current in the coil that was included in the prior current path is not changed. In this manner, six commutation sequences, or phases, are defined for each electrical cycle in a three phase-motor, as shown in Table A.

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Table A

Phase	Current Flows From:	Current Flows To:	Floating Coil
1	A	B	C
2	A	C	B
3	B	C	A
4	B	A	C
5	C	A	B
6	C	B	A

[10] When the motor is turning, rotation of the rotor induces a back electromotive force EMF voltage **e** in each of the coils or windings of the motor. Such back EMF is represented by the Bemf voltage sources in **FIG. 2**. With respect to whichever phase is currently floating, the back EMF voltage **e** in that phase is monitored to determine when to advance the communication sequence. More particularly, the back EMF voltage **e** in the floating coil is monitored to determine when it crosses zero, at which point the position of the rotor is assumed to be known. The point at which the back EMF voltage **e** crosses zero is referred to as the "zero crossing." Each time a zero crossing is detected, the motor advances in its commutation sequence by 30 electrical degrees (by one phase of Table A).

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[18] **FIG. 5** is a schematic diagram of a precondition circuit for winding A of the motor illustrated in **FIG. 4**, according to an embodiment of the present invention;

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[19] **FIG. 6** is a schematic timing of a precondition circuit and the zero-crossing detector ***52*** arranged for compensating the induced signals ***Va***, ***Vb***, and ***Vc*** from the three windings of the motor illustrated in **FIG. 4**, according to an embodiment of the present invention; and

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[23] The motor ***20*** comprises three windings or coils ***A***, ***B***, ***C***. Each winding has a respective inductor ***La***, ***Lb***, ***Lc*** and line resistance ***Ra***, ***Rb***, ***Rc***. The three windings may be connected in a star ("Y") configuration having a center tap ***CT***, or in a delta configuration (not shown). Embodiments of the invention may be applied to either. For each coil, a pair of switches ***Xsa***, ***Xga***, ***Xsb***, ***Xgb***, ***Xsc***, ***Xbc*** (collectively "switch(s) ***X***") connect a free end of a coil (also referred to as a coil tap) at ***Va***, ***Vb***, ***Vc***, to supply ***Vs*** and GND voltages, respectively. The switches are typically power transistors such as Mosfets or the like. A reverse biased diode ***Dsa***, ***Dga***, ***Dsb***, ***Dgb***, ***Dsc***, ***Dgc*** (collectively "diode(s) ***D***") is placed in parallel with (or may be inherently within) each of these switches. The diodes are power rectifiers, and typically serve to protect the switches and windings against induced voltages exceeding the supply or ground voltage. As described in more detail below, during PWM-off states, the voltage drop across the diodes ***D*** has been found to cause the center tap voltage V_{CT} to deviate from zero which, in turn, creates undesirable variances in measurement of the back EMF voltage **e**.

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[24] Continuing to refer to **FIG. 2**, it will be described below, by way of example, how the diodes ***D*** deviate the center tap voltage ***CT*** from zero during a PWM-off state. For this example, it is presumed that the motor ***20*** is in its first phase of a six-phase commutation sequences, wherein current flows from winding A to winding B, while winding C is left floating. Further, it is presumed preferably that during the PWM-off state, the PWM signal does not turn on the switch ***Xga*** coupling winding A to ground. In this manner, during the PWM-off state, all of the current freewheeling from winding A to winding B passes through diode ***Dga***. By not turning on, during the PWM-off state, the switch that couples the high winding (*e.g.* the winding "from" which current is flowing in a given

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commutation phase) to ground, there is reduced switching loss and noise introduced into the motor ***20***. It will be appreciated, however, that the present invention may be applied to motors which turn on the switch (*e.g.* ***Xga***) coupling the high winding to ground during PWM-off periods, except that in such circumstances the precondition circuit ***50*** is appropriately adjusted to take into account the fact that all of the current during the freewheeling period is not passing through the diode (*e.g.* ***Dga***) alone.

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[26] If windings A and B are conducting current, winding C is floating and the terminal voltage ***Vc*** may be detected. When the transistor ***Xga*** is turned off, the current freewheels through the diode ***Dga***. During this freewheeling period, and because there is no current in winding C, coil ***Lc*** induces a back EMF voltage $\boldsymbol{e_c}$ measurable at coil tap ***Vc*** along with any other voltages present in winding C.

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[27] When summing the voltages around winding C; $v_c = e_c + v_n$. The induced signal v_c at coil tap ***Vc*** equals the back EMF signal $\boldsymbol{e_c}$ only when v_n equals zero (or V_{CT} as shown in **FIG. 2**). In fact, v_n is typically not zero because of an offset or distortion introduced by components of the motor driver.

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For winding A, we have

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$$v_n = 0 - v_d - ri - L\frac{di}{dt} - e_a \qquad (1)$$

For winding B, we have

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$$v_n = v_{mos} + ri + L\frac{di}{dt} - e_b \qquad (2)$$

Where v_d is the forward voltage drop of the diode ***Dga***, v_{mos} is the voltage drop on MOSFET ***Xgb***, v_n is the center tap voltage (***Vct*** of **FIG. 2**), $_r$ is the resistor ***R*** of the phase, L is the inductance of the winding, and **e** is the induced back EMF voltage (***Bemf*** in **FIG. 2**) of the winding.

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Adding equations (1) and (2), we get

$$2v_n = v_{mos} - v_d - (e_a + e_b) \qquad (3), \text{ and}$$

$$v_n = \frac{v_{mos} - v_d}{2} - \frac{e_a + e_b}{2} \qquad (4)$$

Also from the balanced three-phase system, we have

$$e_a + e_b + e_c = 0 \qquad (5)$$

From (3) and (4),

$$v_n = \frac{v_{mos} - v_d}{2} + \frac{e_c}{2} \qquad (6)$$

So, the terminal voltage Vc,

$$v_c = e_c + v_n = \frac{3}{2}e_c + \frac{v_{mos} - v_d}{2} \qquad (7)$$

If we ignore the second term of (7), the induced signal v_c at coil tap ***Vc*** is a function of the back EMF voltage e_c. However, especially at low speed and low voltage, the back EMF voltage e_c is very small. Accordingly, one-half of the diode voltage of approximately 0.5 volts will significantly affect the induced signal v_c for a system driving a 12-volt motor. Thus, the second term of equation (7) plays a significant role.

For a low voltage MOSFET, Rd is very low and its Vmos can be ignored, so (7) can be rewritten as,

$$v_c = e_c + v_n = \frac{3}{2}e_c - \frac{v_d}{2} \qquad (8)$$

[28] The above equations demonstrate that the induced signal v_c at the coil tap ***Vc*** is proportional to the back EMF e_c of winding C with the exception of one-half of the voltage across the diode ***Dga***, shown as voltage ***Vd*** in equation (8). As described below, an embodiment of the claimed invention provides a precondition circuit for compensating or offsetting the effect of diode ***Dga***, or compensating for any other distortion in the induced signal v_c at coil tap ***Vc***.

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[30] Referring briefly back to **FIG 2**, in systems not having the precondition circuitry ***50***, the zero-crossing signal ***30*** was typically obtained by comparing the floating-phase coil-tap voltage, such as voltage ***Vc***, with a reference voltage ***Rref*** by way of a comparator ***35***. While for sake of example only winding ***C*** is shown to be coupled to a comparator ***35*** for detecting zero crossings, it will be appreciated that each winding ***A***, ***B***, and ***C*** is coupled to a comparator for this purpose. In especially low-voltage and/or low-frequency applications, it has been determined that because the slope of change of the coil-tap voltage ***Va***, ***Vb***,

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and ***Vc*** as it approaches zero crossing is very gradual, accurately detecting the time a zero-crossing actually occurs can be difficult. In particular, with a gradual change in coil-tap voltage around zero crossing, the actual timing of the zero crossing is often difficult to determine in view of the inherent standard deviation/offset of the comparator ***35***.

[31] **FIG. 4A** illustrates a driver circuit for a brushless DC motor ***100***, according to an embodiment of the present invention. The motor ***100*** is substantially similar to the motor ***20*** described above with reference **FIG. 2** and, therefore, common elements will not again be discussed. However, in addition to the elements described above, the motor ***100*** of the present invention includes a precondition circuit ***50*** that includes networks ***50a, 50b,*** and ***50c***, coupled respectively to the coil taps ***Va***, ***Vb***, and ***Vc*** for each winding. As described in detail below, the precondition circuit ***50*** includes circuitry for offsetting or compensating the coil-tap voltage ***Va***, ***Vb***, and ***Vc*** from the effect of the diodes ***D***. An output of the precondition circuit ***50*** is coupled to a zero-crossing detection circuit ***52***. The zero-crossing detection circuit ***52*** may, for example, take the form of the comparator ***35*** described above with reference to **FIG. 2** or other known circuits known in the art for detecting zero crossings.

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[32] **FIG. 5** is a schematic diagram of a network ***50a*** for winding ***A*** illustrated in **FIG. 4**, according to an embodiment of the present invention. However, it will be appreciated that similar networks ***50b*** and ***50c*** are coupled to windings ***B*** and ***C*** as shown in **FIG. 4**. The networks ***50a-c*** of the present embodiment includes circuitry for offsetting the voltage offset of the diode ***D*** from the induced signal ***v***, so that the outputted back EMF signal ***Ea*** is substantially directly proportional to the back EMF voltage ***e***. As used herein, "back EMF signal" means a signal related to the back EMF voltage ***e***, particularly with respect to the zero crossing feature. For example, as shown in equation (9) below, the "back EMF signal" ***Ea*** may be 3/2 of the back EMF voltage ***e***.

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[33] The network ***50a*** includes a node ***Nva*** for receiving an induced signal ***Va***, a node ***NEa*** for outputting the back EMF signal ***Ea***, a control voltage ***Vcon***, and resistors ***R1***, ***R2***, and ***R3***. Resistor ***R1*** is coupled between the node ***Nva*** and a node ***Na'***, the resistor ***R2*** is coupled between the control voltage ***Vcon*** and the node ***Na'***, and the resistor ***R3*** is

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coupled between the node ***Na'*** and the node ***NEa***. The voltage ***Vcon*** and the resistors ***R1*** and ***R2*** are selected to compensate for the offset voltage ***Vd/2*** that is introduced into the induced signal ***Va*** by the diode ***D*** such that Vcon x R1/(R1+R2)=Vd/2.

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Specifically, for winding ***A***:

$Ea = Va' = Va + Vcon * R1/(R1 + R2)$ (9)

Also from equation (8)

$$Va = \frac{3}{2}e_a - \frac{v_d}{2} \qquad (10)$$

If we select Vcon, R1, and R2 such that

$$Vcon * \frac{R1}{R1 + R2} = \frac{Vd}{2} \qquad (11)$$

Then, combining equations (9) and (10) results in

$$Va = \frac{3}{2}e_a - \frac{v_d}{2} + \frac{v_d}{2} = \frac{3}{2}e_a \qquad (12)$$

As demonstrated by the above equations, the back EMF signal ***Ea*** is directly proportional to the back EMF voltage e_a when negligible current flows through ***R3***, which is a current limiting resistor. In a driver controlling a 12-volt motor, typical values may be 1k ohms for ***R1***, 10k ohms for ***R2***, 4.7k ohms for ***R3***, and 5 volts for ***Vcon***.

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[34] **FIG. 6** is a schematic diagram of the precondition circuit ***50*** including networks ***50a-c***, and the zero-crossing detector ***52***, arranged for compensating the induced signals ***Va***, ***Vb***, and ***Vc*** for the three windings ***A***, ***B***, and ***C*** of the motor ***100*** of **FIG. 4**, according to an embodiment of the present invention. The precondition circuit ***50*** is an extension of the network ***50a*** of **FIG. 5**, where three resistive networks are provided to compensate the three induced voltages ***Va***, ***Vb***, and ***Vc***. Alternatively, each network may receive a different voltage ***Vcon***, and/or include different resistor values. In one embodiment, R1=R4=R7, R2=R5=R8, and R3=R6=R9.

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[35] Continuing to refer to **FIGS. 4 and 5**, and using winding ***A*** as an example, in order to offset the effect from the diode ***Dga*** on the signal ***Va*** at the coil tap ***Va***, the network ***50a*** includes a voltage-divider circuit. Node ***Nva*** is coupled to the coil tap ***Va*** to receive the induced voltage ***Va***. Node ***NEa*** is coupled to an input of the zero-crossing detector ***52***. The

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resistive network of ***R1*** and ***R2***, and ***Vcon*** offsets the induced voltage ***Va*** of the winding ***A*** coil tap ***Va*** by Vd/2, providing the induced signal ***Va'*** at node ***Na'*** and signal ***Ea*** at node ***NEa*** that are directly proportional to the back EMF voltage ***e*** of winding ***A***. In this manner, the network ***50a*** is able to add a constant voltage to the induced signal ***Va*** that substantially eliminates the effect of the diode ***D***.

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[36] It will be appreciated that while values for ***Vcon***, ***R1*** and ***R2*** are stated above for sake of example, other values could have been chosen to achieve a similar result. Further, it will be appreciated that while the networks ***50a-c*** are shown to be formed of a voltage-divide circuit, the present invention is intended to cover any circuit configuration active or passive which serves to offset the value of the diode ***D*** or any other distortion, and is not limited to a voltage-divide circuit. Additionally, as mentioned above, in the present example during a PWM-off state, the switch ***Xga*** in the high winding is not turned on in order to minimize switching loss and noise. Thus, in the example leading to equation (9) the effect of the diode ***Dga*** was shown to be VDga/2. It will be appreciated, however, that the present invention is suitable for use in other motor configurations where, for example, the ground switch (*e.g.* ***Xga***) for the high winding is turned on during a PWM-off state. In such cases, the effect of the diode ***D*** on the coil-tap voltage will differ from the VDga/2 described in the above example. Accordingly, in such alternative embodiments, components of the precondition circuit ***50*** are correspondingly adjusted to offset the effect of the "on" ground switch ***Xga*** by an appropriate amount as can be readily determined by one in the art.

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[37] The operation of the precondition circuit ***50*** and the networks ***50a-c*** are now described with reference to **FIGS. 4-6** according to an embodiment of the invention. The motor ***100*** is driven by a PWM signal ***110*** that is applied to the motor ***100*** in one of several conventional manners. For example, in one embodiment, during PWM-on states, the high switch (*e.g.* ***Xsa***, ***Xsb***, ***Xsc***) for the "from" winding of the commutation sequence and the ground switch (*e.g.* ***Xga***, ***Xgb***, ***Xgc***) for the "to" winding of the commutation sequence are turned on. During the following PWM-off state, the high switch in the "from" winding is turned off and all of the freewheeling current is allowed to pass through the diode (*e.g.* ***Dga***, ***Dgb***, ***Dgc***) in the "from" winding to ground through the ground switch in the "to" to winding. Such a current path during the PWM-off state is representatively depicted in **FIG.**

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4 by current path i_{off}. By not turning on the ground switch in the "from" winding during the PWM-off state, it is possible to avoid switching delays and noise. However, it will be appreciated that the present invention is suitable for motors ***100*** that operate in any switching mode.

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[39] During PWM-off states, zero-crossing detection occurs by providing the induced signal from coil taps ***Va***, ***Vb***, and ***Vc*** for the floating phase to nodes ***Nva***, ***Nvb***, and ***Nvc***, respectively, of the precondition circuit ***50***. The networks ***50a-c*** of precondition circuit ***50*** then offset the induced signal for the effect of the diode ***D*** and the resulting signals ***Ea***, ***Eb***, ***Ec*** are proportional to the back EMF voltage **e** for each winding. For instance, in the present example, the precondition circuit ***50*** adjusts the induced signal at the floating phase coil taps ***Va***, ***Vb***, and ***Vc*** by an amount substantially equal to an amount by which the voltage at the center tap ***Vn*** (also shown as V_{CT}) is deviated from zero as discussed above with reference to equations (6) & (7).

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[41] FIG. 7 is a theoretical timing diagram illustrating the compensated signals ***Ea***, ***Eb***, ***Ec*** at the nodes ***NEa***, ***Neb***, and ***Nec*** of precondition circuit ***50*** of **FIG. 6**, and resulting output from the zero-crossing detection circuit ***52*** in a motor, according to an embodiment of the invention. For sake of simplicity, the theoretical data shown in **FIG. 7** presumes the high frequency PWM signal is removed. As shown, with the precondition circuit ***50*** compensating for the offset caused by the diode ***D***, the output of the zero-crossing detection circuit ***52*** that controls advancement of the commutation sequence of the motor is substantially reflects the desired 60-degree switching intervals. Accordingly, an aspect of the present invention provides for smoother switching through the commutation sequence, which in turn provides a more efficient motor that is less likely to jitter or stall.

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